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Project Summary

Fabric Filtration Analyses for Three Utility Boiler Flyashes

H. A. Klemm, J. A. Dirgo, and R. Dennis

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A major objective of this program was to augment the present data base for modeling fabric filter systems designed for the control of inhalable particulate (IP) emissions from coal-fired boilers. Emphasis was placed on the determination of K_2, the flyash specific resistance coefficient, and a_c, a parameter describing fabric cleanability. Fabric filter design, operating, and performance data were analyzed with the assistance of utility personnel from Harrington and Monticello Stations in Texas and Kramer Station in Nebraska. Supplementary laboratory determinations of K_2 were made for flyashes produced by the above facilities because K_2 values could not be estimated from field data alone. Based on laboratory tests it was determined that flyash surface deposits underwent negligible porosity changes for fabric pressure losses <2000 N/m². Additionally, a simple field procedure was developed to measure K_2 directly with the aid of heat resistant membrane filters and a Method 17 in-situ sampling probe. Detailed analyses and modeling trials indicated that K_2 and a_c estimates developed from routine compliance or acceptance tests were too rough for dependable modeling although provided useful guidelines. Laboratory-estimated K_2 values ranged from 0.89 to 3.79 N-min/g-m while a_c values varied from 0.01 to 0.52. Special pilot tests and equipment are recommended to obtain "modeling quality" data inputs.

Introduction

Background

The expectation that the control of particulate emissions from the combustion of coal in utility, industrial, and commercial boilers will entail progressively stricter emissions regulations suggests that fabric filter systems will assume a more pronounced role in the future. For those situations where fabric failure as the result of thermal stressing, chemical corrosion, or moisture condensation cannot be avoided, electrostatic precipitation and/or wet scrubbing may provide acceptable alternatives.

The ease with which a new fabric filter system can be brought on-line sometimes depends more upon good luck than upon the application of solid design and operating principles. There are many reasons for the occurrence, and frequently the persistence of field shakedown problems although lack of information certainly plays a key role. In some cases, there may not be a full understanding of the process to be controlled or exactly what takes place during the operation of a large multi-chambered fabric filter system. Furthermore, even when the system designer is properly informed from the technical perspective, there may be an unfortunate lack of solid quantitative data relating to the key parameters determining the overall filter system performance.

With the present availability of experimental modeling techniques for predicting filter system operation, there exists a developing capability to eliminate some of the guess work in filter design by

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augmenting the data and experience inventories of fabric filter vendors and designers. The model (developed by GCA) can predict fabric filter performance in terms of pressure loss and dust penetration based on system design and operating parameters. Limited validation tests, Table 1, have indicated agreement between predicted and measured values for fabric filter pressure loss and flyash penetration at two coal-burning utilities (Sunbury Station of Pennsylvania Power and Light and Nucla Station of Colorado-Ute Electric Association).

Table 1. *Measured and Predicted Performance for Woven Glass Bags with Coal Flyash*

	Percent penetration	
	Measured[a]	Predicted[a]
Nucla, Colorado	0.21	0.19 (1.52)[b]
Sunbury, Pennsylvania	0.15	0.20
	Resistance-kPA	
	Measured	Predicted
Nucla, Colorado		
Average, cleaning and filtering	1.03	0.97
During cleaning only	1.7	1.52
Maximum just before cleaning	1.16	1.16
Minimum just after cleaning	0.85	0.72
Sunbury, Pennsylvania		
Average, cleaning and filtering	0.64	0.62
During cleaning only	0.71	0.66
Maximum just before cleaning	0.71	0.66
Minimum just after cleaning	0.56	0.57

[a] *Averaged over cleaning and filtering cycles*
[b] *During cleaning cycle only*

Effective applications of current modeling technology are restricted to systems where two important variables, the specific resistance coefficient for the dust (K_2), and the cleaning parameter (a_c) for a specific dust/fabric combination, are accurately defined. The former term, K_2, affords a measure of the pressure loss through the dust deposit on a fabric while a_c provides an indication of the degree to which the superficial dust layer is dislodged from the fabric. From a physical perspective, a_c depicts the fraction of the superficial dust layer removed from the fabric surface as a result of the fabric cleaning action. Generally, a_c may range from values as low as ~0.05 for collapse and reverse-flow cleaning to levels of ~0.5 for filter systems using vigorous mechanical shaking.

Unfortunately, numerical values for K_2 and a_c have been determined for relatively few dust/fabric combinations and the capability to calculate accurately K_2 and a_c based solely upon theoretical considerations is very limited. Direct measurement of the above terms is advocated, preferably by well controlled laboratory experiments and, given the opportunity, by specially designed field tests on full scale equipment.

Purpose of the Program

The primary purpose of this project was to examine alternative approaches for obtaining improved or new estimates of K_2 and a_c values typifying real field situations. It had been proposed that for selected field operating conditions and with prior estimates for one of these parameters, the steady-state filtration parameters (such as air-to-cloth ratio, inlet dust concentration, baghouse temperature, total number of compartments, number of compartments cleaned at one time, cleaning frequency and cleaning duration) might be used to estimate the other parameter.

In those cases where the available data did not permit individual estimates of K_2 and a_c, various compatible [K_2–a_c] pairs for these parameters were inferred from the steady-state field operating and performance parameters. The above approach proved to be of little value, however, unless supporting evidence could be obtained to narrow the range of the resultant pairs.

It was recognized at the outset of this study that the use of raw field data without the advantage of special equipment modifications or controlled changes in operating mode should not be expected to produce other than interim working values serving as temporary guidelines until more sophisticated measurements could be performed. It was also suspected and later demonstrated that certain groupings of field data that initially appeared promising were not amenable to analysis. On the other hand, it was believed that if the determination or assumption of rational values for K_2 and a_c, based upon laboratory tests and/or comparable field measurements, led to predicted pressure loss and dust penetration values in fair agreement with field observations, the viability of supporting modeling procedures would have been validated. It was further recognized that the laboratory estimates for K_2 were based on the redispersion and filtration of flyash collected from baghouse hoppers. Because particle size simulation problems are always a possibility when a bulk dust sample is reaerosolized, laboratory estimates of K_2 were not automatically assumed to reflect the K_2 for freshly deposited flyash in the field.

Program Results

The laboratory phase of this program involved the determination of K_2 values at typical field filtration velocities for coal flyash samples supplied by the baghouse operators of three cooperating utility groups: Southwestern Public Service Company (SPS), Harrington Station; Texas Utilities Generating Company (TU), Monticello Station; and the Nebraska Public Power District (NPPD), Kramer Station. Flyash samples were filtered at field filtration velocities on used, but cleaned, woven glass fabrics (Menardi-Southern 601 TUFLEX-Teflon B Coating) such as those commonly used in the field. Changes in pressure loss were observed as the dust accumulated (mainly upon the fabric surface) to areal densities up to ~800 g/m². Average K_2 values for the reaerosolized flyashes were 2.75, 0.89, and 3.79 N-min/g-m, respectively for SPS, TU and NPPD. Limited tests at two velocities showed that K_2 values for the SPS flyash were dependent upon filtration velocity but to a lesser extent than estimated in earlier studies for a cyclone boiler flyash.

A very significant outgrowth of the laboratory test program were the results of concurrent K_2 measurments in which membrane filters (HA Millipore) were used as the substrate for the deposited flyash layer. It was observed that the slopes of the pressure loss/filter loading curves were almost completely linear from their origins (zero dust loading) to the maximum dust loading. First, the characteristic concave-down form normally found with woven glass fabrics during the early fabric loading period was no longer present because there was no preliminary pore filling phase such as found with most woven glass fabric and membrane filters are shown in Figure 1. Because of

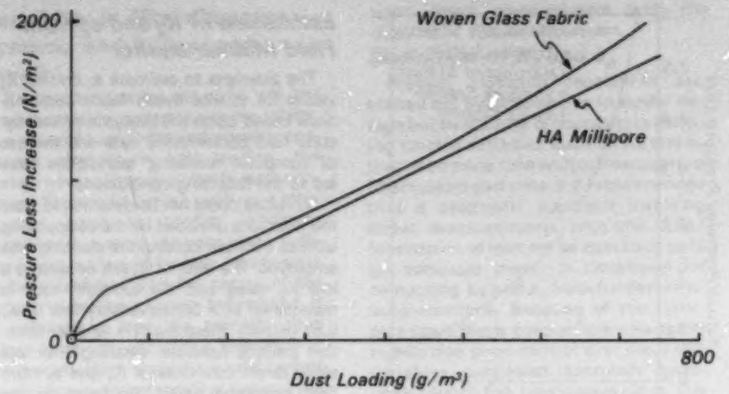

Figure 1. Typical pressure loss increases due to surface dust deposits for coal flyash filtration with woven glass fabric and HA Millipore filters.

the linear slope of the membrane filter combinations was not seen with the membrane filter substrate. Characteristic pressure loss/dust loading curves for woven glass fabric and membrane filter curve, it appears that flyash layers per se undergo no compression due to increased pressure gradient over nominal ranges up to 2000 N/m². The curvature observed for the woven glass fabric can be attributed to the gradual compression of the bulked filbers within the woven fabric substrate.

The results of the analyses of field performance data from the co-operating power stations indicated that because essentially continuous cleaning was required at all plants, no direct field estimates of K_2 were possible. Field data included the inlet flyash concentration, the average air/cloth ratio (or filtration velocity), and the average baghouse pressure loss values before and after sequential cleaning of all compartments as well as the total number of compartments, the off-line time for a compartment during cleaning, the total time to clean all compartments, and the reverse flow velocity. Only in those instances where extended filtration intervals without cleaning allow for the development of a uniformly distributed dust layer can K_2 be infered directly from field operating data. Otherwise, it is necessary to use the laboratory generated K_2 values (with their recognized limitations) not only to characterize their field counterparts but also to determine the cleaning parameters, a_c.

The above technique was applied to selected data sets that appeared to represent the steady-state filtration conditions for which the GCA fabric filter model has been designed. By treating the values of K_2 and a_c as data input in conjunction with design, operating, and cleaning parameters customarily used in the modeling process, predicted values were generated for average pressure loss and dust penetration properties for the field systems. In view of the assumptions involved, the agreement between observed and predicted pressure losses (roughly 10 to 40 percent deviations) tends to support the analytical approach, Table 2.

The level of agreement is somewhat deceptive, however. The initial calculation of a_c is based not only upon field operating parameters, including pressure loss, but also upon a laboratory derived estimate of K_2 that may not be truly representative of K_2 in the field. It is emphasized that the primary objective of this program was to derive field estimates of a_c (and possibly K_2) for dust/fabric combinations not previously studied in detail at the pilot plant level. Hence, the extent to which a confirming prediction of pressure loss or penetration agrees with the actual field measurement indicates the reasonableness of the calculated a_c value. It must be realized that the accuracy of predicted performance and/or estimated air/cloth requirements is highly susceptible to errors in K_2 and a_c. Because of the mathematical role played by a_c in predictive modeling, predicted pressure losses are highly sensitive to small changes in a_c.

Table 2. *Summary of Predicted and Measured Pressure Loss and Penetration Values for Utility Boilers at Harrington, Kramer and Monticello Stations Based on Estimated K_2 and a_c Values*

Boiler designation	Boiler load level, MW	K_2[a] N-min/g-m	Cleaning parameter, a_c[b]	Average pressure loss, N/m²		Percent penetration	
				Predicted[c]	Measured	Predicted[c]	Measured
Harrington No. 2	156	3.0	0.08	580[d]	700	0.33	0.5
	324		0.16	1080	1400	0.37	to
	351		0.11	1600	2200	0.42	0.6
Kramer No. 2	23		0.52	745	700	0.61	—
Kramer No. 2	16		0.21	570	670	0.34	—
Kramer No. 3	14		0.07	525[d]	750	0.39	0.23
Kramer No. 3	14	3.7	0.20	490	600	0.29	0.04(0.30)[e]
Kramer No. 3	19		0.17	545	625	0.51	0.10(0.04)[e]
Kramer No. 3	22		0.47	800	950	0.35	0.02(0.10)[e]
Kramer No. 4	35		0.49	700	675	0.60	—
Monticello No. 1 or 2	475	0.97	0.32	1735	2750	0.80	—

[a] *Based on laboratory measurements with resuspended flyashes. Reported at 25°C, 0.61 m/min.*
[b] *Based on hand calculations outside of computer model.*
[c] *Predicted by computer model using indicated K_2 and a_c values.*
[d] *Model value corrected by supplemental model equations.*
[e] *Values in parentheses based upon alternate interpretation of field data.*

particularly when a_c is in the 0.1 range as shown graphically in Figure 2.

At the present time it cannot be stated whether the curve form of Figure 2 represents a failing in the modeling process to describe the complexities of filtration with sequential cleaning or merely the need to define low a_c values at a higher accuracy level. Note that actual and predicted pressure losses were much closer for the Sunbury and Nucla tests, Figure 2.

A second observation arising from the field analyses was that the computed values of a_c in some cases fell below the 0.1 value constituting the lower limit for model application. (Actually the model will function with a_c entries of less than 0.1, but will treat them mathematically as if they were 0.1.) Although this prob-was solvable by long-hand appoximation techniques, it is suggested that the model application be broadened by reducing the lower limit for a_c. When the modeling procedure was modified by the use of supplemental equations to show the true impact of $a_c = 0.07$, a much improved prediction of pressure loss resulted, Table 3.

Table 3. *Pressure Loss Predictions for SPS, Harrington No. 2 Boiler With Slightly Used Fabric*

Cleaning parameter a_c	Average pressure loss (N/m^2)	
	Predicted	Measured
0.10	400[a]	700
0.07[b]	666[c]	700

[a] *Based on automatic treatment by model of $a_c = 0.07$ as $a_c = 0.1$.*

[b] *Actual a_c value calculated from field and laboratory data.*

[c] *Based on supplemental equations and hand calculations performed outside of model.*

Conclusions

An intensive review and analysis of field data supplied by three electric utility groups aided by supporting laboratory assessments of flyash samples from these sources have led to the following conclusions.

Laboratory K_2 Measuring Techniques

The non-linearity observed with pressure loss versus fabric loading curves with many glass fabrics results from compression of the fabric and not the dust cake over the typical ranges of pressure loss, <2000 N/m^2 (8 in. water), encountered in the field. Although the degree of curvature involved does not lead to serious computational error for most flyashes, the ability to distinguish between substrate compressions and dust cake compaction will facilitate the modeling of other dust/fabric combinations. In cases where fabric compressibility introduces a significant amount of curvature in the drag/dust loading relationship, a single correction such as that used to correct K_2 for velocity effects may be appropriate.

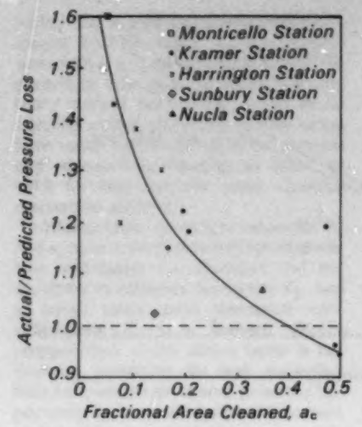

Figure 2. Ratio between actual and predicted pressure loss values for increasing a_c values.

The technique of using a membrane filter as the dust collecting substrate may provide a simple, economical means for direct field measurement of K_2. A filter circle consisting of Teflon or other appropriate membrane material can be mounted in an in-stack filter holder with provisions to measure pressure loss across the filter over a 30 to 60 minute sampling period. This measurement and the resulting flyash weight gain, determined by subsequent removal of the filter from the holder, will enable simultaneous estimates of both K_2 and local mass concentration. In contrast to similar measurements with woven fabrics or other substrates where the initial curve path is always curvilinear, the membrane approach requires only two pressure measurements, initial and final, and a net dust weight to establish the slope (and K_2) for the pressure loss-fabric loading curve.

Estimation of K_2 and a_c from Field Measurements

The attempts to estimate a_c and/or K_2 values for various flyash/fabric combinations based upon the analyses of steady-state field performance data and the use of computer modeling techniques have led to the following conclusions.

K_2 values could not be determined from the field data provided by the cooperating utilities because continuous cleaning was employed. If a dust or flyash possesses a low K_2 value and the air/cloth ratio is maintained at a conservatively low level, 0.61 m/min, there may be lengthy filtration periods between cleaning that will allow direct estimates of K_2 and a_c from field operating data. The need to use laboratory estimates of field K_2 values introduces errors relating to probable differences in particle size parameters. Use of the field K_2 technique involving Teflon membrane filters and in-stack collection of the flyash as a conventional testing procedure would greatly improve the accuracy of K_2 measurements and hence the reliability of modeling predictions.

The estimation of a_c values from a combination of laboratory K_2 measurements and typical field measurements associated with compliance test data depends not only upon the representativeness of the K_2 value, but also upon the accuracy of measured field operating parameters, such as pressure loss, air flow, inlet concentration, and adherence to indicated cleaning parameters. Those dust/fabric combinations, which, in conjunction with certain filtering and cleaning parameters cause small a_c values, will produce the greatest errors in predictive modeling because of the inherent sensitivity of pressure loss to small changes in a_c in the low, ~0.1, a_c range. The apparent occurence of a_c values less than the present lower limit of 0.1 set for the GCA filtration model suggests minor changes in the model structure.

The results of the current analyses afford rough estimates of the probable behavior of given flyash/fabric combinations. These results demonstrate the need for specialized measurement programs based upon laboratory or field pilot scale testing to determine accurately the values for the K_2 and a_c parameters. These terms should not be computed from theoretical considerations except for guideline purposes until the dust permeability and adhesion phenomena can be described in terms of practically and easily measured parameters.

Variability in Filter Cleaning Systems and Boiler Load Levels

The present model structure will not predict variable system behavior where, due to rapid load shifts and possibly concurrent changes in inlet loading, the system never achieves a steady-state condition. The model can be used on a step-by-step basis to predict moderate variability in system behavior when sufficient time is allowed for near steady-state to be established and the nature of the system variability is known beforehand. It is emphasized that the problem cited above does not represent a deficiency in the model design since the model cannot predict how a boiler (and filter system) will be operated by plant personnel.

Recommendations

Fabric Filtration Model

Continued experimentation with the fabric filter model designed for use with coal-fired boilers has suggested the following modifications or improvements. It is recommended that the capability of the computer program to deal with difficult-to-clean dusts be extended by decreasing the lower limit for the cleaning parameter from 0.1 to 0.05 or less. In some cases, low values for a_c may result from the decision to operate a baghouse at the lowest possible pressure loss, the latter often accomplished by more frequent cleanings.

The model capability to correct K_2 values for momentum compaction (and reduced porosity) produced by increasing filtration velocities should be modified to include the unique effects associated with individual dusts. This should be accomplished by performing bench or pilot plant drag versus fabric loading tests with experimental redispersions of the field aerosols of interest. Any variability in K_2 attributable to velocity (impact) effects would then be expressed empirically in the form $K_2 = \phi(V)^{n<n<1}$.

Based upon the results of laboratory K_2 measurements made during this program with membrane filters as the substrate, it is suggested that non-linearities in drag/loading curves result from gradual fabric compressibility. When these non-linearities are significant, allowances could be made within the model by applying a compressibility factor (similar to the K_2-velocity relationship described above). Again, until it is possible to predict how a specific dust/fabric will behave, the necessary corrections must be based upon direct measurements with the dust/fabric system of concern.

Definition of K_2 and a_c

Present modeling capabilities are limited not by deficiencies in model design but by the lack of accuracy in defining certain variables such as K_2 and a_c that determine how well or how poorly a filter system performs. It is recommended that a pragmatic approach involving direct measurements with the dust/fabric pairs of interest be exercised until an adequate theory is developed for computing K_2 and a_c from fundamental considerations. Because of the favorable scale factor coupled with the ability to exercise good control over *most* test variables, continued laboratory measurements of the type discussed in this report afford the best immediate solutions.

However, the ever present difficulty of not usually being able to generate a laboratory aerosol that simulates the true disperse state of the field aerosol requires caution in the use of any laboratory-derived filtration parameters. Therefore, it is also recommended that correlations be sought between laboratory and field generated values for relevant filter system variables. To pursue the above task most effectively, specially modified real filter systems or, preferably, pilot scale field installations that use a slipstream of the real gas stream as the test aerosol source are the recommended approaches to determine the correct scale factor for translating laboratory-derived values to their field counterparts.

Concurrent measurements should be made at bench scale and pilot levels (supported by field tests if feasible) to identify and quantify the fundamental variables that control key modeling parameters such as K_2 and a_c.

It is recommended that the membrane filter concept for K_2 determination that was applied successfully in the laboratory be adapted for field applications where temperature and corrosion problems must be considered. Although commercially available components can be used, some basic engineering and design will be required to assure flexibility in field applications. It is proposed that the filter holder be attached to a sampling probe to reduce the probability of line losses. Teflon or other inert membranes or possibly all-glass paper may serve as the basic filter or substrate. Pressure lines should be included so that the pressure loss across the dust layer and filter can be determined during the sampling period.

H. A. Klemm, J. A. Dirgo, and R. Dennis are with the GCA Corporation, Bedford, MA 01730

***Joseph A. McSorley** is the EPA Project Officer (see below)*

The complete report, entitled "Fabric Filtration Analyses for Three Utility Boiler Flyashes," (Order No. PB 80 214182; Cost: $10.00, subject to change) will be available from:

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